(UNCLASSIFIED TITLE)

PULSED LIGHT INVESTIGATION
FOURTH INTERIM ENGINEERING REPORT

SEPTEMBER - NOVEMBER 1961

Report No. RLI-3854-4

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ILLUSTRATIONS

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1. INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

Target seekers which operate in space must be capable of detecting and tracking targets of one square meter in area at a range of 100 miles. The presently used airborne active radar seekers have a limited potential for attaining these requirements, hence alternate approaches must be considered. Theoretical calculations indicate that the optical seekers (optical radars) are capable of attaining the required range. Although the development work in the optical radar field has been in progress for several years, a transmitting light source with sufficient intensity has not been developed. Therefore the most promising approaches in the development of reliable and sufficiently intense pulsed light transmitting tubes are being investigated.

1.2 OBJECTIVE

The objective of this investigation is to obtain a pulsed light source for investigating the use of light as the source of energy in an active target seeker for missile guidance. By using a very small light source (1 millimeter in diameter) with extremely high radiant flux density, a very narrow (20 minutes of arc) and intense transmitting

light beam may be obtained. In the presence of the masking effect of solar radiation, targets can be detected at useful ranges only with beam intensities considerably greater than can be obtained with present equipment. To achieve such an increase in intensity, extensive development is required on light sources of increased brightness.

1.3 REPORT SUMMARY

By using vinyl plastic sleeving as the wall of the spark discharge chamber, repeated discharges in oil at an energy level above 20 joules have been sustained. The spark duration, as measured by its luminous output, is approximately 2 μsec with the particular capacitor and electrode structure used.

With the higher energy level of these discharges, tungsten and other materials previously used have been shattered and it has been necessary to use high speed steel tool bits for electrodes.

2. SPARK DISCHARGES IN MINERAL OIL

2.1 SUMMARY OF PREVIOUS RESULTS

In the preceding work on this project all the spark source configurations that have been built were characterized by two serious deficiencies: low energy and erratic operation. Although discharges in oil have shown significant improvements in brightness over those in air, their practical usefulness has been limited by the small total energy available and the difficulty in controlling the time and the voltage at which the discharge occurs.

Work during this quarter has centered on removing these two limitations, to the exclusion of any other than the most elementary measurements of luminous output or the electrical characteristics of the source capacitors.

In the previous work, the envelope containing the working fluid--oil in this case--has been either glass or fused quartz, or a plastic such as lucite or nylon. For the brittle materials such as glass the maximum energy which could be dissipated was about 1.5 joules, the actual figure being dependent on the size and shape of the envelope. The maximum energy that could be dissipated while still maintaining reasonable life for the envelope was considerably less than this figure, being about 0.1 joule. With plastic materials the tolerance was somewhat greater, the maximum being about 3.8 joules. The nylon discharge chamber shown in Figure 2 of the Third Interim Report could be

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operated for long periods of time at one energy level of 1 joule. It was not able to withstand for any great length of time a discharge of 3.7 joules.

Both the evidence of these experiments and theoretical considerations based on knowledge of the rate of energy dissipation in the spark suggest that the destructive force is in the form of a shock wave. The breaking of the rubber diaphragm at the back of the nylon discharge chamber mentioned above also suggests that there is in addition a pressure increase sustained for a much greater time than can be accounted for by a shock wave.

2.2 VINYL TUBE DISCHARGE CHAMBER

The destructiveness of the shock wave can be largely eliminated by choosing for the envelope a material which is elastic enough to deform with the force without injury to itself. Among the various materials of this type, the clear vinyl plastic sleeving commonly used for electronic equipment was the most readily available. To test its possibilities the discharge chamber shown in Figure 1 was constructed.

This chamber withstood an energy level of 2 joules for a considerable time without apparent damage so the storage capacitor was increased to 1.75 μf, providing 22 joules at the maximum voltage of 5000 volts. Since the actual voltage at which the discharge occurs is rather erratic, varying

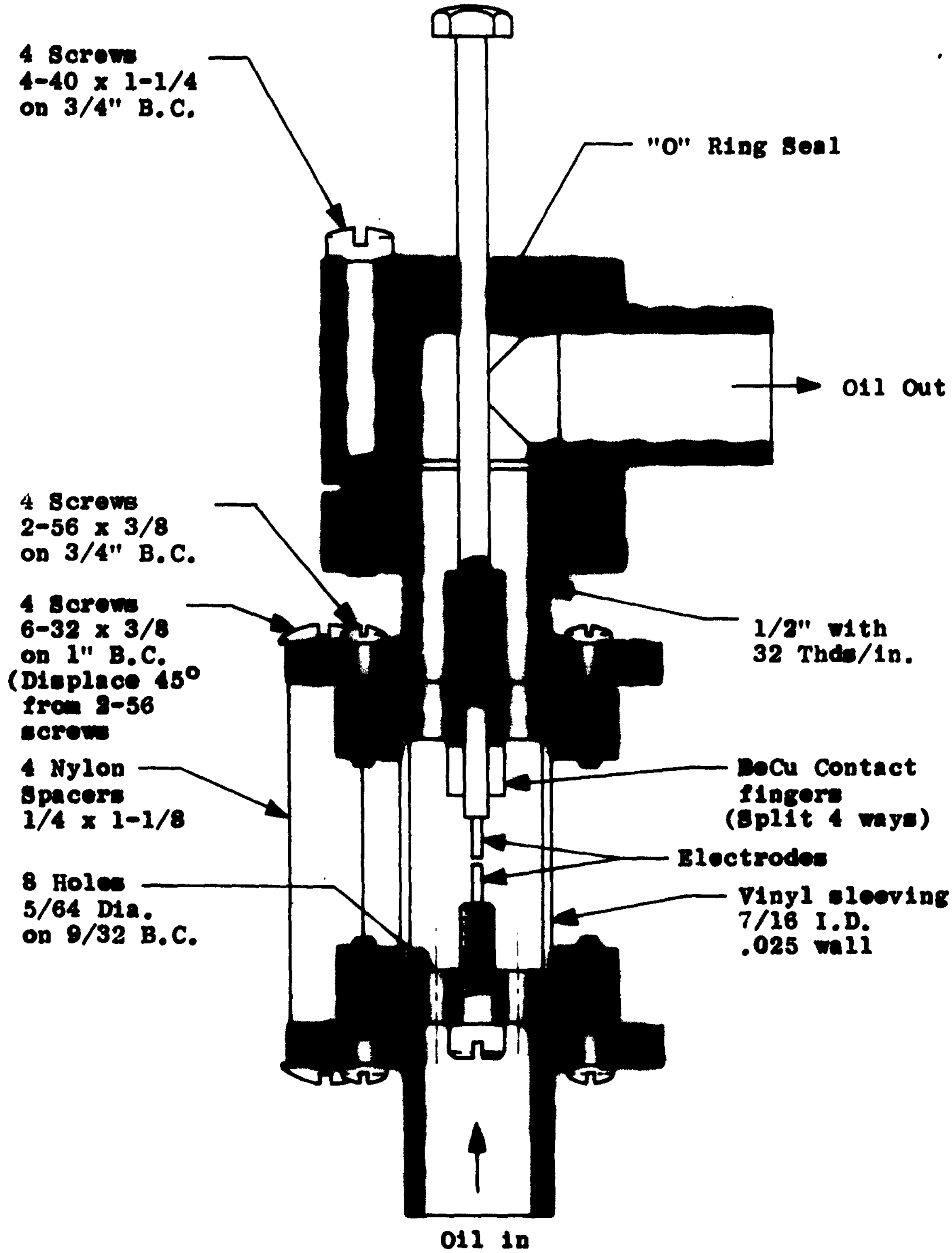

FIGURE 1 - HALF-INCH VINYL TUBE DISCHARGE CHAMBER

from 3000 to 5000 volts, the average energy per pulse is somewhat less than the maximum. A value of 12 to 15 joules is a reasonable average. The life of the plastic sleeving under these conditions was limited, individual pieces withstanding from 20 to 100 discharges.

In an effort to improve the life of the plastic, several variations of the original design were tried. Some of these are shown in Figure 2. First the two brass rings shown encircling the inner plastic sleeve were installed. This resulted in a noticeable increase in life, the factor being estimated to be 2. (It was believed that accurate statistical studies at this time would be meaningless.) It was observed that the plastic sleeving frequently failed where the brass rings restrained it (circumferentially), while the failure was generally longitudinal when the rings were not used.

It was believed that a shock wave alone would not cause the splitting of the sleeving that occurred when thr rings were not used. This appeared to be more likely the effect of the expanding bubble of gas formed by the spark and which was estimated to amount to about 0.5 cc at room temperature and normal atmospheric pressure. The brass rings were expected to prevent this and although they did show an improvement it appeared that they created their own problems

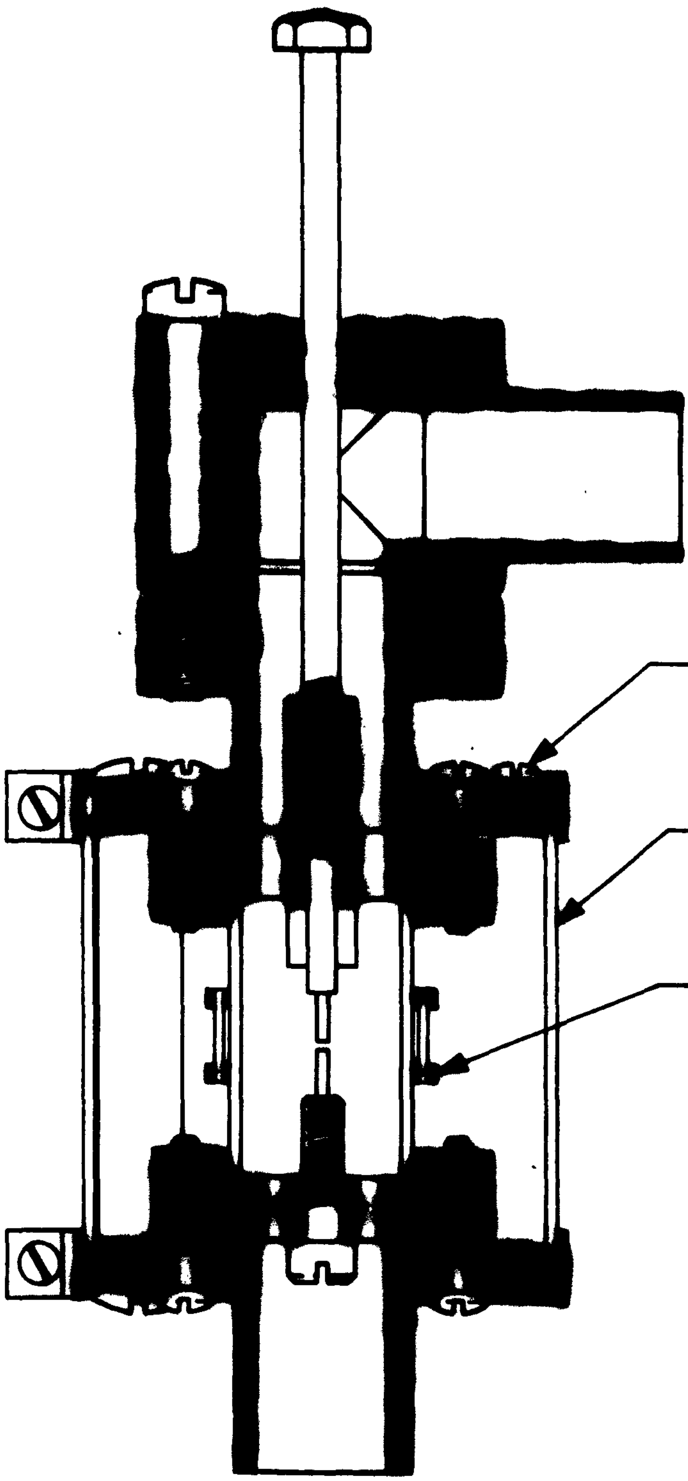

FIGURE 2 - REINFORCED VINYL TUBE DISCHARGE CHAMBER

by providing a rigid surface against which the shock wave could compress the plastic sleeving and cut it.

This explanation is of course purely conjecture. It was, however, the basis for the next step which consisted first of removing the rings and enclosing the entire structure, including the plastic sleeve, in a still larger (1-1/4-inch i.d.) plastic sleeve (Fig. 2). The space between the two sleeves was filled with oil and all bubbles worked out. It was believed that this would provide some reinforcement against the pressure built up by the gas bubble and at the same time a very strong resistance to the shock wave. This resistance, however, would be evenly distributed so the tendency of something solid to cut into the plastic, as the brass rings apparently did, would be eliminated. The results of this test were unsatisfactory in that no significant improvement over the unrestrained vinyl sleeve could be noted.

The brass rings were then replaced on the inner sleeve and the space between the two sleeves again filled with oil. The results were similar to those obtained with the brass rings alone, without the outer sleeve and intervening oil cushion. This result was quite unexpected since it had been believed that the layer of oil between the two sleeves would restrain the inner sleeve against shock without producing a

high localized stress where the rings touched it. The rings could in turn resist the later pressure buildup which the outer oil layer was unable to resist.

Since it seemed impossible to restrain the effects of the discharge with any of the available materials, the possibility of a very soft resilient material was considered. This would merely restrict the oil flow to the inner sleeve but would transmit shock or expansion to the outer chamber without any significant force other than compression on itself. The only transparent material conveniently available was polyethylene in thicknesses from 0.0007 to 0.002 inch. This proved to have very short life, lasting for only a few discharges before rupture. The type of rupture was unexpected however, in that instead of a simple split in the material there were a number of ragged breaks, most of which showed evidence of heating to the melting point. In addition there were numerous small blisters and pinholes formed in the material.

Two explanations come to mind to explain such behavior. The first is that the expanding bubble of hot gas reaches at least 1/4 inch out from the spark and retains enough energy to melt the polyethylene. A less plausible explanation is that the destruction is caused by a shock wave which causes

both local heating and high stress in the material. The concentration of blisters at some points remote from the spark, but so situated that reflections would tend to concentrate sonic energy, favors such an explanation.

Throughout all of these tests the 1.25-inch outer plastic sleeve remained undamaged. Thus it was natural to consider the use of this alone as the wall of the discharge chamber, omitting the inner sleeve. This step was taken reluctantly because the greater volume of such a structure would require at least 5 times the oil flow to sweep the chamber free of dirt and bubbles before the next discharge. While a new chamber permitting greatly increased oil flow was being constructed, tests were continued with the old structure. The inner plastic sleeve was removed to permit checking of the performance with the outer sleeve alone. Since the clamping arrangement was unsatisfactory and tended to cut the plastic, the results of tests were not considered to be conclusive. However, they did indicate that much longer life could be obtained.

The new discharge chamber shown in Figure 3 provides for greatly increased oil flow and heavier electrodes. A 1.25-inch diameter, 0.040-inch wall vinyl sleeve installed on it has withstood several hundred discharges at an energy level of 15 to 25 joules. The ultimate life of this sleeve has not

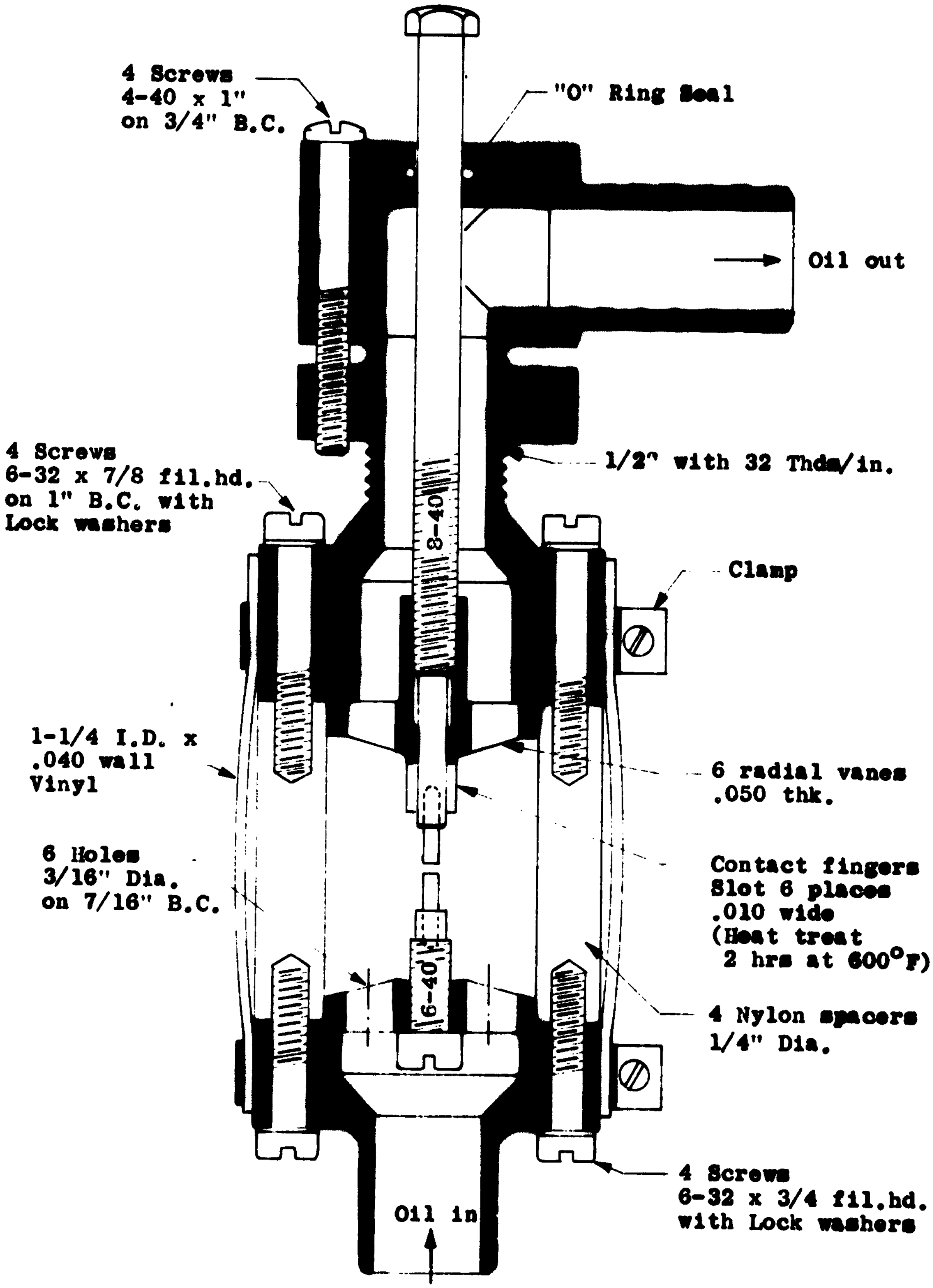

FIGURE 3 - LARGE VINYL TUBE DISCHARGE CHAMBER

been determined since it is believed that certain other problems associated with oil immersed spark sources required solving first.

It may be noted that the spring fingers making contact to the movable electrode are much heavier in this design than those shown in Figure 1. The design shown in Figure 1 used an electrode holder of 0.080-inch diameter with contact being made by beryllium copper fingers. This material was in the "as drawn" condition having an ultimate strength of about 75,000 psi. This was not sufficient to maintain good electrical contact and arcing started at the fingers. The explosive force of this arcing soon expanded the fingers until they did not make contact, leaving the threads to carry the current. The threads then rapidly burned off.

In the source shown in Figure 3, the diameter of the electrode holder has been increased to 0.125 inch and more contact fingers have been provided. Also, the material has been heat treated to develop an ultimate strength of 150,000 to 175,000 psi. There has been no evidence of arcing on this electrode holder.

Some apprehension was felt with regard to the light absorption in the large amount of oil and plastic sleeving used in this structure. The absorption of a 2-inch sample of the oil used was measured. This sample was contained in a cell

having fused quartz endplates. For wavelengths of 5000 Å and greater, the transmission of this cell was approximately 75%. When correction is made for reflection losses at the ends (at least 5% each end) it is apparent that the absorption loss in the 0.6 inch of oil used in the discharge chamber is negligible at these wavelengths. Below 4500 Å the transmission dropped rapidly. Even in this region, however, it is estimated that the absorption in 0.6 inch will not exceed 50%. Tests of a single thickness of the 1/2-inch diameter vinyl sleeving indicated a transmission of 79% or better at all wavelengths greater than 4000 Å.

2.3 ELECTRODE MATERIALS

The sources built previously in this study used tungsten electrodes, generally 0.030-inch diameter. There were several instances of breakage of these electrodes but since they were infrequent no particular significance was attached to the phenomenon. In some of the structures, flexing due to misalignment of the parts, plus embrittlement of the tungsten in brazing it in place, could easily explain the breakage.

When the discharge energy was raised to the 10- to 20-joule range, however, breakage became so frequent that it could not be ignored. Electrodes sometimes lasted only 5 or 10 discharges. The diameter was increased to 0.045 inch but very little improvement was noted. The type of break varied

with the particular sample of material used. The one sample of 0.030-inch diameter wire stock available invariably produced a splintery break with many fractures along the axis of the electrode. This was consistent with the idea of long fibrous crystals produced in drawing the tungsten wire. The 0.045-inch stock generally produced a break square across the section of the rod although longitudinal fracture was sometimes also evident. Gradual crumbling of the end also occurred. Both lots of material available in 0.045-inch diameter were in short lengths, centerless ground for use as electrodes for welding or similar purposes, thus the orginal drawing or swaging process is not known for them.

Several expedients were tried in an effort to improve the strength of these electrodes. The ends of the 0.045-inch rod were fused in an inert atmosphere (argon) but this merely produced a square break just below the fused zone. A piece of the 0.030-inch wire was silver soldered into an 0.007-inch thick platinum sleeve. After a few discharges the sleeve split open and the spintery fracture characteristic of this wire appeared.

Materials other than tungsten were tried. Molybdenum wire shattered in a manner similar to the 0.030-inch tungsten. Nichrome, inconel and platinum produced a mushroom shaped head and quickly bent out of line. Electrodes were ground

from a tungsten boule which was grown (hopefully) as a single crystal and, containing no grain boundaries, is considerably less brittle than that produced by other methods. This material can be machined with carbide tipped tools at normal machining feeds and speeds. Although it was somewhat more satisfactory than any of the previous materials, breakage was still too frequent for a useful device, even when the diameter was increased to 0.062 inch.

Finally, electrodes were ground from 18% tungsten high-speed steel tool bits. Although erosion of these electrodes is somewhat more rapid than when pure tungsten is used, they have sufficient life to permit meaningful data to be obtained on the performance of the sources and the other problems that exist. It is probable that some of the high tungsten content alloys would provide better life but for the present this field cannot be investigated.

It is significant to note that the wear on these electrodes for discharges in oil is of a different nature than that observed when the discharge occurs in air. The air discharge almost always tends to produce a rounded tip on the electrode, with considerable evidence of oxidation and erosion for a distance down the sides. In oil, the tip of the electrode becomes concave and there is little evidence of erosion at the sides. The cavity in the tip is bright and appears free of oxide.

2.4 CONTROL OF BREAKDOWN VOLTAGE

Another problem which has made all measurements on spark sources under oil very difficult and uncertain has been the erratic nature of the discharge. All the oil immersed sources used so far have depended for their initiation on simple breakdown of the gap as the storage capacitor charged. As is well known, dielectric breakdown of liquids is a very uncertain phenomenon, successive tests of the same sample frequently showing a 50% variation. Where the breakdown produces severe contamination, as is the case when considerable energy is dissipated in the discharge, even greater variation may be expected. The presence of gas bubbles makes the situation worse.

It has commonly been observed in this study that a discharge at the maximum of about 5000 volts on the storage capacitor (22 joules) would be followed rapidly by one or more discharges in the 2000-to 3000-volt range (3.5 to 8 joules). Following this the gap would not break down at the maximum of 5000 volts until the electrodes were moved closer together. A small change might then reduce the breakdown voltage to 3000 volts, with a gradual increase to 5000 as the electrodes were eroded by a succession of 5 or 10 discharges. Since the spacing of the electrodes is only about 0.010 inch, it can be seen that very little erosion is needed to increase the breakdown voltage prohibitively.

Spark Discharges in Mineral Oil

Making quantitative measurements in the face of such irregular behavior is almost impossible and it is for this reason that performance as reported above has been given in very vague terms. Three means have been considered for improving the repeatability of the discharges. The most simple of these is to increase the operating voltage of the storage capacitor. At the higher voltage, the gap spacing will be greater and a given amount of erosion will produce a proportionately smaller change in the breakdown voltage. It seems reasonable to expect that some improvement in luminous efficiency of the source may also result from this change. Operating at 5000 volts the gap spacing is only about 0.010 inch so it is apparent that there is considerable shadowing of the output by the 0.060-inch diameter electrodes. With greater spacing this shadowing will be reduced.

Higher operating voltage will not solve the problem of premature breakdown of the gap during the charging time immediately following a discharge. As mentioned above, this occurs in the interval before the oil flow through the chamber can sweep out the dirt and gas bubbles formed by the discharge. If the charging time constant is made long enough to prevent appreciable voltage buildup before the chamber has been swept clean, the interval between discharges is unreasonably long. A timing circuit has been considered

which will hold off the voltage for a few seconds until the chamber is clean, and then rapidly charge the capacitor to the desired voltage. There are several possible charging circuits that might be used with the timer, the most satisfactory depending somewhat on the operating voltage of the system and the components available.

2.5 TRIGGERING METHODS

Even with the above mentioned changes it is still to be expected that there will be considerable variation in the breakdown voltage of the gap. Either alone or in combination with these changes it seems desirable to incorporate some form of trigger to permit positive control of the breakdown. Several trigger electrode structures have been built at this laboratory for use with discharges in gasses and the one which proved most satisfactory seems also to be applicable to the oil immersed sources. This design, shown in Figure 10 of the Third Interim Report and repeated here as Figure 4, provides completely separate regions for the two discharges. Thus the trigger gap need not contain oil with its attendant problems. Construction of this structure was started during the previous quarter but work on it was suspended to devote more time to the promising sources using a vinyl plastic envelope. For trying out trigger structures, however, it will provide a satisfactory configuration with less work than would be involved in starting a complete new design.

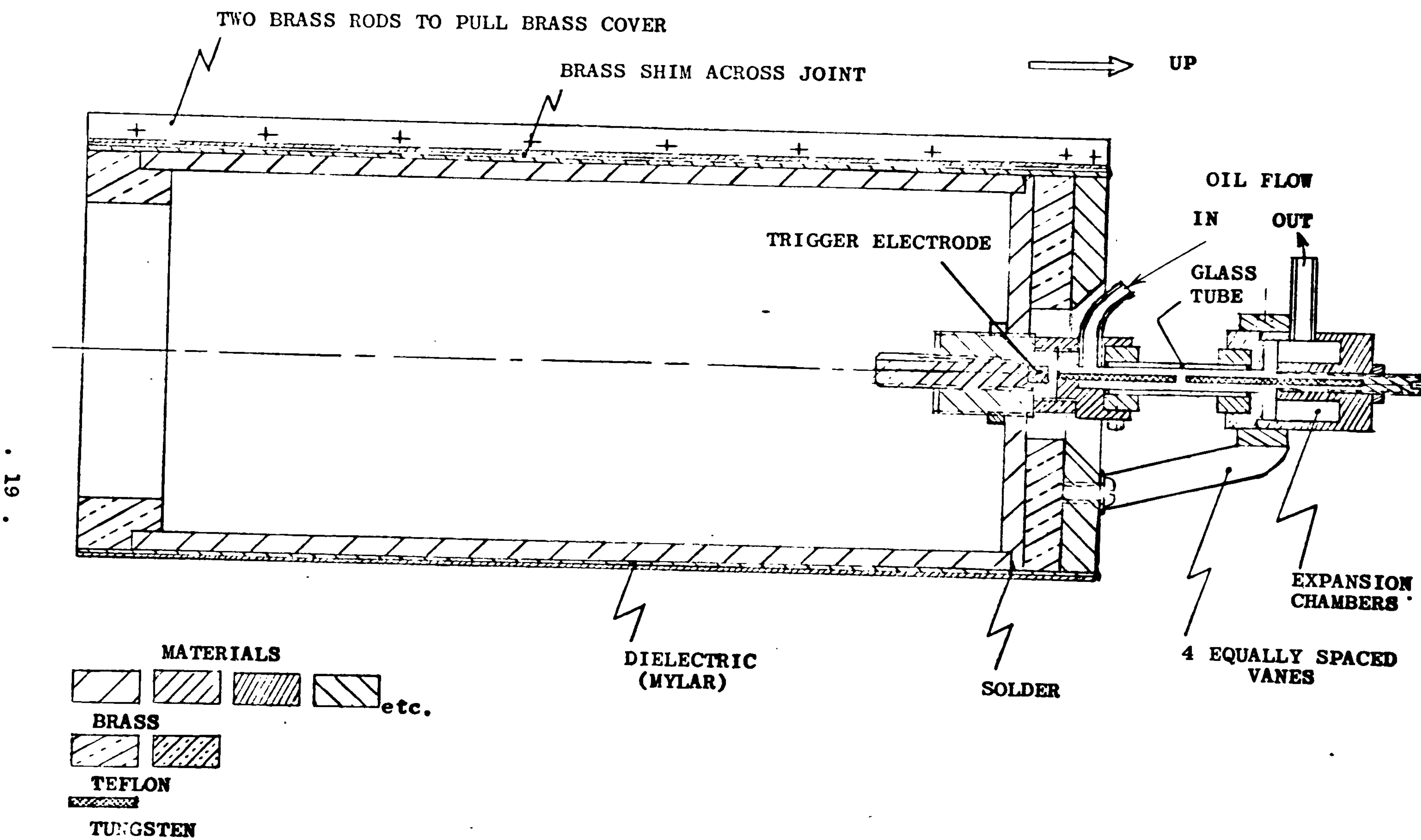

FIGURE 4 - TRIGGERABLE SOURCE

Spark Discharges in Mineral Oil

Another method which has been considered for triggering involves the use of rf power in the 1000- to 3000-Mc range. By operating at the resonant frequency of the electrode structure, a relatively high voltage can be induced across the gap to initiate breakdown. However, a pulse power of several kilowatts is required and since experimental changes in the structure will produce major changes in the resonant frequency, it is not considered feasible to obtain the necessary rf power sources at this time.

2.6 LUMINOUS OUTPUT

As mentioned above, very little work has been done on the measurement of the luminous output of the discharges because of the large variations obtained between pulses. However, to obtain an approximate figure for the spark duration, and thus the power level, a few tests were made. The duration of the luminous output above 50% of peak brightness was in all cases less than 2 μsec, frequently being as low as 1.5 μsec. Tailoff to less than 10% of peak required about 5 μsec from the start of the pulse. The curve of luminous intensity was slightly slower than for brightness, remaining above 50% of peak for about 2 μsec.

3. CONCLUSIONS AND RECOMMENDATIONS

There are no conclusions or recommendations to be reported at this time.

4. WORK FOR THE NEXT PERIOD

Having achieved a container capable of withstanding discharges in the 10- to 20-joule range, it is now of prime importance to obtain sufficiently reliable triggering to make the source a useful device. As indicated in Section 2.5, a trigger structure has been designed and most of the parts fabricated but it has not yet been assembled and tested. This work will take precedence over all other. Following these tests, it is anticipated that a similar trigger will be incorporated into the circuit of the source shown in Figure 3, permitting reliable and consistent measurements to be made of its luminous output. This will be done both with oil as the medium and, for comparison, with air.

Capacitors capable of providing a discharge energy of 12 joules at 10 kv have been received and the possible improvement to be obtained at this voltage will be determined.

Several ideas have been brought forward for increasing the energy level above the present limit of some 20 or 30 joules. There is of course the brute force method of simply increasing the size of the discharge chamber. This is not an attractive solution, however. It is anticipated that some form of air entrapped in foam rubber or in thin rubber or plastic capsules will be tried.